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ATMOSPHERIC OPTICAL PROPAGATION COMPARISONS DURING MAGAT-80.(U)

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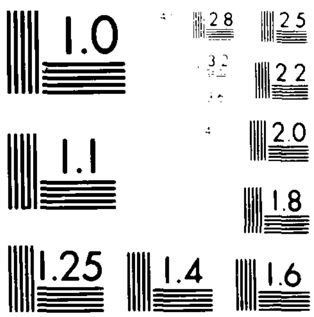

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TECHNICAL REPORT

ATMOSPHERIC OPTICAL PROPAGATION

COMPARISONS DURING MAGAT-80

C. W. FAIRALL,

G. E. SCHACHER and K. L. DAVIDSON

Environmental Physics Group

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Prepared for: Naval Ocean System Center
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There are three atmospheric processes responsible for the degradation of the transmission of optical images and electro-optical energy: aerosol extinction, molecular absorption, and turbulent distortion (scintillation and beam wander). As a part of the Marine Aerosol Generation and Transport experiment (MAGAT-80), light transmission characteristics (refractive-index structure function parameter, C_N^2, and total extinction coefficient, α)

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were measured optically on a 13.3 km path across Monterey Bay. C_N^2 and α can also be calculated from micrometeorological data (aerosol spectra, turbulence and mean meteorological parameters). This report is a compilation of the preliminary analysis of path-averaged (aircraft) and midpoint (ship) micrometeorological data, including calculations of the relevant optical parameters for comparison with the optical measurements.

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ABSTRACT

There are three atmospheric processes responsible for the degradation of the transmission of optical images and electro-optical energy: aerosol extinction, molecular absorption, and turbulent distortion (scintillation and beam wander). As a part of the Marine Aerosol Generation and Transport experiment (MAGAT-80), light transmission characteristics (refractive-index structure function parameter, C_N^2, and total extinction coefficient, α) were measured optically on a 13.3 km path across Monterey Bay. C_N^2 and α can also be calculated from micrometeorological data (aerosol spectra, turbulence and mean meteorological parameters). This report is a compilation of the preliminary analysis of path-averaged (aircraft) and midpoint (ship) micrometeorological data, including calculations of the relevant optical parameters for comparison with the optical measurements.

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A. INTRODUCTION

Light propagating through the atmosphere is not only scattered and absorbed by aerosols and molecules, but the wavefronts are deflected and distorted by turbulence. The evaluation and application of optical, electro-optical, and laser systems requires reliable data and a tested physical model of these atmospheric effects.

NPS personnel recently participated in a large-scale field experiment designed to improve and verify certain overwater models of these atmospheric processes for the U.S. Navy. The experiment, Marine Aerosol Generation and Transport (MAGAT), was the brainchild of Professors Kenneth L. Davidson and Gordon E. Schacher of the Environmental Physics Group at the Naval Postgraduate School (NPS) in Monterey, California. Other government installations involved in the planning of the experiment were the Naval Ocean Systems Center and the Naval Environmental Prediction Research Facility. The Electro-Optics/Meteorology (EO/MET) Program, the High Energy Laser (HEL) Program, and the Naval Air Systems Command provided funding for the project. MAGAT was held from April 28 to May 9, 1980, in the vicinity of Monterey Bay.

The first phase of the experiment dealt with the compatibility of optical and micrometeorological propagation theory. In cooperation with the NPS Physics Department, Optical Propagation Group, direct measurements of optical extinction and scintillation across Monterey Bay were compared with both marine surface layer model predictions and aerosol and turbulence data obtained at the midpoint of the optical path from the Research Vessel R/V ACANIA. In addition, path averages of aerosols and turbulence were obtained by flying an instrumented aircraft

the entire length of the 13.3 kilometer optical path at altitudes varying from 3.5 to 20 meters above the sea surface. The aircraft measurements were made in cooperation with Airborne Research Associates of Boston, Massachusetts. This report is a preliminary analysis of the aircraft and ship measurements for the first phase.

The second phase of the experiment involved an ambitious attempt to extend dynamic models of the evolving marine atmospheric boundary layer to include aerosol and turbulence profiles. This phase of the experiment, conducted in a region 30 to 50 nautical miles off the coast of Monterey, required periodic monitoring of aerosol and micrometeorological variables from the surface to 5 kilometers. These duties were shared by the aircraft and the R/V ACANIA (which utilized various remote sensing techniques). The analysis of the second phase of the aircraft measurements will be covered in a separate report.

B. BACKGROUND

1. Optical Parameters

The two atmospheric optical properties of primary interest are total extinction and refractive-index structure function parameter, C_N^2. The extinction has several components: molecular scattering and absorption ($\beta = \beta_s + \beta_a$) and aerosol scattering and absorption ($\alpha = \alpha_s + \alpha_a$). Thus, the extinction parameterizes the loss of light energy as it is scattered out of the beam or absorbed by the molecular and particulate constituents of the atmosphere. The distortion and tilt of image wave fronts by atmospheric turbulence is parameterized by C_N^2.

We can write C_N^2 as a function of temperature (C_T^2) and water vapor (C_Q^2) turbulence structure function parameters

$$C_N^2 = (79 \times 10^{-6}\ P/T^2)^2 (C_T^2 + 0.113\ C_{TQ} + 3.2 \times 10^{-3}\ C_Q^2) \qquad (1)$$

where P is the pressure in mb, T the absolute temperature and C_{TQ} the temperature-humidity cospectral structure function parameter. C_N^2 can be obtained in three ways: 1) optical measurement, 2) measurement of C_T^2, C_{TQ}, and C_Q^2, and 3) calculation of C_T^2, C_{TQ}, and C_Q^2 from bulk meteorological data (water temperature, air temperature, humidity and wind speed).

The total extinction ($\alpha + \beta$) can be measured optically by determining the reduction in beam intensity over some suitable optical path. The separate components can be calculated from micrometeorological data. The molecular extinction can be obtained from the LOWTRAN model developed by the Air Force Geophysics Laboratory (Selby et. al, 1978). The aerosol extinction can be calcualted from the aerosol spectral density, N(r).

$$\alpha = \int_0^\infty \pi r^2 \, E(n,\lambda) \, N(r) \, dr \tag{2}$$

where r is the particle radius, $E(n,\lambda)$ the total scattering efficiency at wavelength, λ, and refractive-index, n.

2. Turbulence Scaling Parameters

Since the details of surface layer scaling are covered in previous reports (Fairall, et. al., 1980) this discussion will be limited to a few basic definitions. Near the surface, the height above the surface, Z, can be normalized by the Monin-Obukhov stabiltiy length, L. We can then represent the micrometeorological properties in terms of scaling parameters and dimensionless functions of $\xi = Z/L$,

$$C_T{}^2 = T_*{}^2 \, Z^{-2/3} \, f(\xi) \tag{3a}$$

$$C_Q{}^2 = Q_*{}^2 \, Z^{-2/3} \, Af(\xi) \tag{3b}$$

$$C_{TQ} = r_{TQ} \, T_* Q_* Z^{-2/3} \, A^{1/2} \, f(\xi) \tag{3c}$$

where T^* and Q^* are the temperature and humidity scaling parameters, $f(\xi)$ is a dimensionless function (Wyngaard et. al., 1971), r_{TQ} is the temperature-humidity correlation parameter (about 0.8) and A is a constant (about 0.6).

The rate of dissipation of turbulent kinetic energy, ξ, can be similarly represented

$$\varepsilon = \frac{u_*^{\,3}}{KZ} g(\xi) \tag{4}$$

where u^* is the friction velocity and K is Von Karman's constant (0.35). The scaling length is given by

$$L = \frac{T}{gK} \frac{u_*^{\,2}}{(T_* + 0.61\ TQ_*/\rho)} \tag{5}$$

where g is the acceleration of gravity and ρ is the density of air.

Note that the scaling parameters are related to the surface fluxes of momentum (τ = Reynolds stress), temperature (Q_o) and water vapor (M_o)

$$\tau = \rho u_*^{\,2} \tag{6a}$$

$$Q_o = -u_* T_* \tag{6b}$$

$$M_o = -u_* Q_* \tag{6c}$$

3. Bulk Parameterization

Although the scaling parameters can be determined from either direct flux measurements or from measurements of C_T^2, C_Q^2, and ε, the difficulty of these measurements has led to the development of a method that utilizes bulk meteorological quantities (wind speed, u, temperature, T, and water vapor density, Q). In this case, the scaling parameter for X (X = u,T,Q) is obtained from the difference in X from

the sea surface (X_s) to some reference height (usually 10m) in the atmosphere.

$$X_* = C_x^{\frac{1}{2}} (X_{10} - X_s) \tag{7}$$

where c_x is the drag coefficient for x (typically, $c_x = 1.3 \times 10^{-3}$ over the ocean). Further details on the bulk method can be found in Davidson et. al. (1980).

C. INSTRUMENTATION

1. Aerosol

The aerosol spectra were measured with optical particle counters made by Particle Measurement Systems (PMS) of Boulder, Colorado. The R/V ACANIA used the standard NPS system consisting of two probes, the classical scattering (CSAS) and the active scattering (ASAS), controlled by a DAS-32 with computer interfacing. This system measures aerosols in 90 size channels from 0.09μ to 14.0μ radius. The aircraft aerosol data were obtained using a PMS model ASSAP on loan from NOSC. This system has 60 size channels from 0.28μ to 14.0μ radius.

2. Aircraft Meteorology

The aircraft micrometeorological parameters are logged on a computer controlled (HP9835) twenty channel data acquisition system. Each parameter is sampled every 2.5 seconds with a two-scan average stored every 5 seconds. The data is stored on magnetic tape cassette with a four hour capacity. A brief description of the micrometeorological data is given in Table 1. Further details on aircraft instrumentation can be found in Fairall (1979).

D. ANALYSIS

1. Aerosol

The aerosol analysis techniques for the ship and aircraft are basically the same. The N(r) spectrum is calculated for half-hour averages on the ship and path averages for the aircraft (about 2 minutes). The spectrum is fit in LOG(N(r)), LOG(r) space with a seventh order polynomial for $0.09\mu<r<7\mu$, with a linear fit for $r>7\mu$. The extinction is calculated using these fits for $0.03\mu<r<30\mu$ on the ship and for $0.1\mu<r<15\mu$ for the aircraft. This calculation is discussed in depth in Schacher et. al. (1980).

The method was developed for the ship system and adapted for use with the aircraft. Because of the greater statistical scatter in the N(r) spectrum from the aircraft probe, the polynomial fit is subject to occasional "instabilities". Should this occur, the polynomial fit will bear no resemblance to the N(r) data. Another symptom of this instability is the occurrence of large polynomial coefficients. Due to the preliminary nature of this report, the data have been left unedited. The reader is cautioned to use common sense when attempting to use these results.

The aircraft and ship aerosol extinctions were compared in a series of flybys. Since the ship system is newer, has a wider range, better sensitivity and is better understood, we decided to correct the aircraft extinctions to agree with the ship. The correction factors are given in Table II.

TABLE I. Aircraft Meteorological Data

Channel	Data	Symbol	Sensor
1	Pressure	P	National Semiconductor
2	Temperature	T	Platinum resistor
3	Temperature	T	Vortex (NRL)
4	Dew Point	T_d	Cooled mirror
5	Sea Surface T	T_s	PRT-5 (IR)
6	Electric Field	E	Radioactive probe
7	-		
8	Refractivity	N	Microwave cavity (NAC)
9	Water Vapor Density	Q	Lyman-α, mean (NRL)
10	Air Speed	U	Hot wire, mean
11	Dissipation		Hot wire, fluctuation
12	N structure funct.	C_N^2	Microwave, fluctuation
13	T structure funct.	C_T^2	Microthermal, fluctuation
14	Q structure funct.	C_Q^2	Lyman-α, fluctuation
15	-		
16	-		
17	-		
18	-		
19	Electrical Conductivity	λ	Flat plate
20	-		

TABLE II. Ratio of Ship to Aircraft

Extinction Coefficient Values

Wavelength, μm	Before 5/4/80	After 5/3/80
0.63	3.8	1.8
0.84	5.2	2.0
1.06	7.1	2.5

These factors are based only on the open ocean comparisons. The Monterey Bay comparisons were not included so that the ship and aircraft optical comparisons could be considered independent. The complete set of correction factors is shown in Fig. 1.

2. Micrometeorology

The methods and equations used to obtain the basic parameters given in Table I have been described in Fairall (1979). Once these meteorological parameters are in hand, one can calculate the scaling parameters (Section B2) using either turbulence or bulk quantities. Since we did not have mean wind speed available for the aircraft, we did bulk calculations using a hybrid method where the dissipation rate, ε, is used to obtain u_* (Eq. 4).

3. Optical Data

The optical extinction ceefficients, as obtained from the optics group, represent total extinction due to aerosols and air molecules. The molecular components were calculated using LOWTRAN IIIB and subtracted from the total to leave only the aerosol extinction. The LOWTRAN values used are given below

Wavelength, μm	0.63	0.84	1.03	1.06
Molecular β, km^{-1}	0.01	0.04	0.00	0.00

A description of the optical measurements is given by Crittenden et. al. (1980).

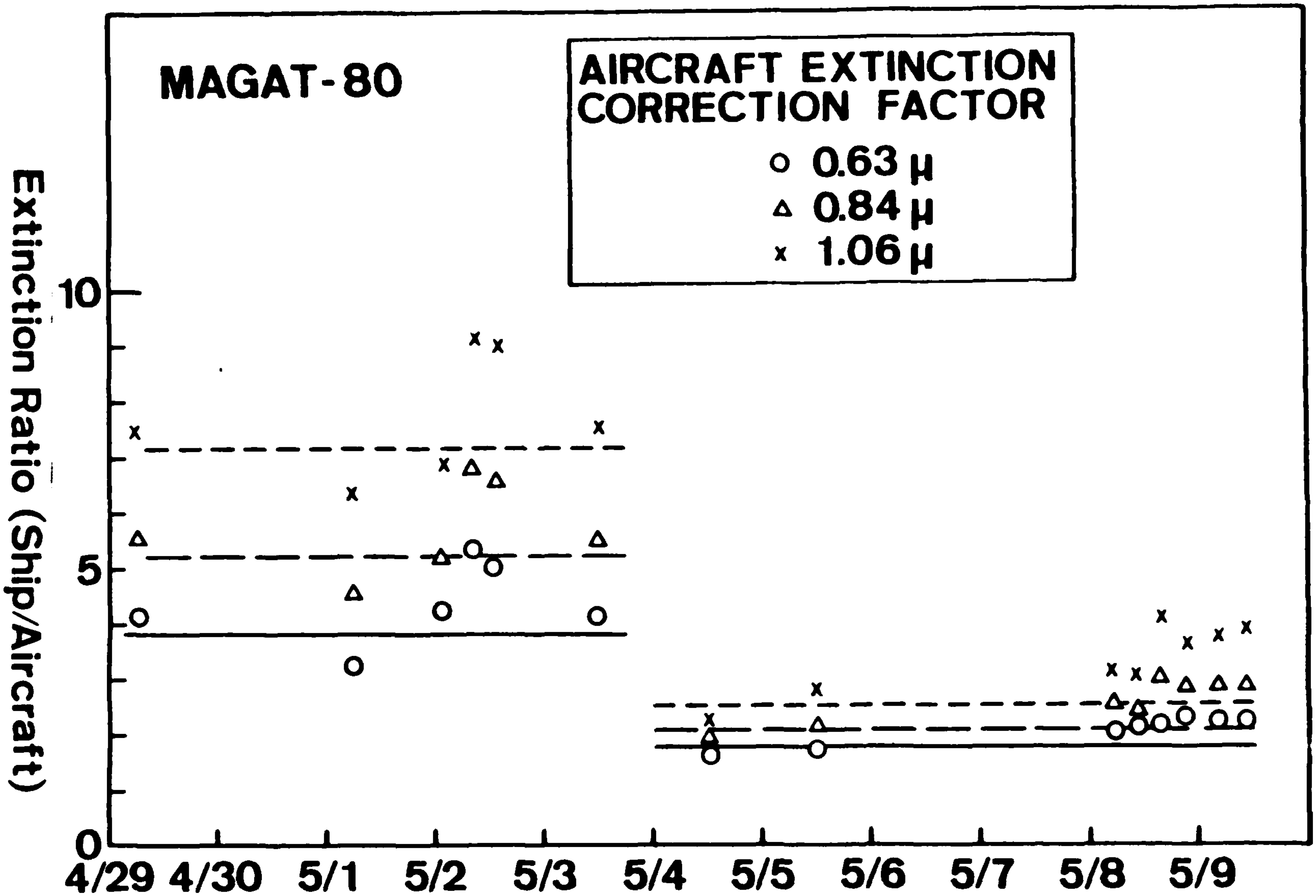

Figure 1. Ratio of ship to aircraft aerosol extinction coefficients. The horizontal lines represent the factors used to correct the aircraft values to agree with the ship.

E. RESULTS

The measurements were made in Monterey Bay along a 13.3 km path from Pt. Pinos to Marina (Figure 2). The R/V ACANIA was located in the region indicated by the square. The aircraft made constant altitude passes along the optical path. Later in the experiment, several passes were made perpendicular to the path. The optical comparison was done on turbulence (C_N^2) and extinction (α). The optical and ship C_N^2 comparison has already been reported (Davidson et. al., 1980) so it will not be discussed here.

1. Aircraft C_N^2 Evaluation

The basic aircraft optical path micrometeorological measurements and bulk calculations of scaling parameters are given in Table III. A more detailed printout is given in Appendix A. The bulk scaling predictions of C_N^2 (Eq. 3 and Fig. 1) are compared with the turbulence measurements in Fig. 3. These results are similar to those obtained from the ship measurements (Davidson et. al., 1980).

2. Aircraft Extinction Comparison

A summary of the aircraft optical path extinctions is given in Appendix B. In Fig. 4 the aircraft aerosol comparison with the optical measurements is shown. Out of nineteen comparison runs (three wavelengths each) only two disagree by more than a factor of two. For the aircraft aerosol data, the average ratio of extinction for aerosols versus optics is 1.0 + 50%, -40%.

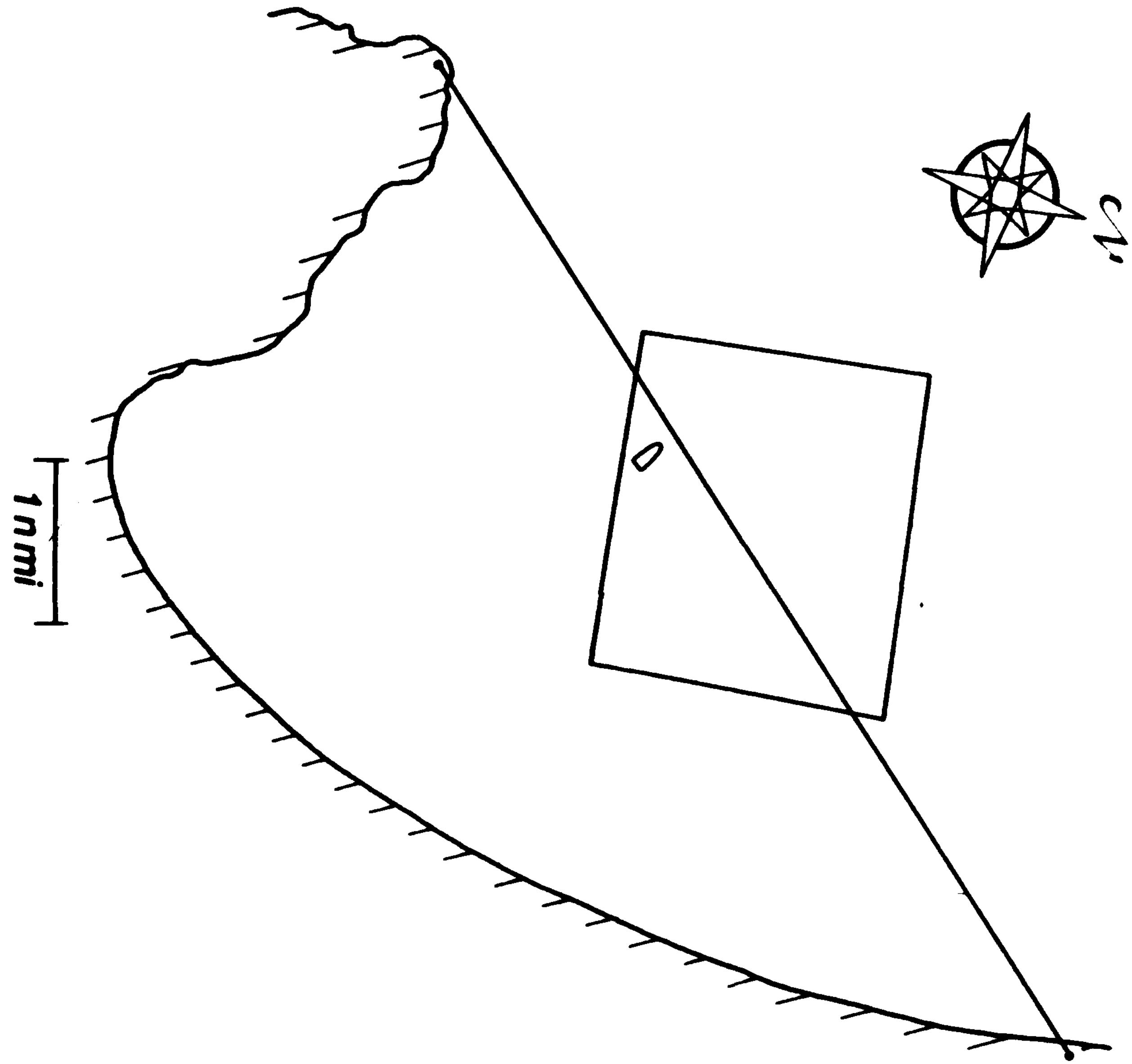

Figure 2. Location of 13.3 km optical path in Monterey Bay. The square indicates the R/V ACANIA operating area for optical comparisons.

TABLE III. Aircraft optical path bulk data and scaling parameters

DATE	#	TIME	ALT	T	TS	q	qS	Z/L	U*	T*	q*	L
04/29/80	1	173155	40	12.4	14.9	7.5	10.6	-2.65E-01	.231	-.098	-.117	-58
04/30/80	2	142010	40	12.1	14.1	7.7	10.1	-8.22E-02	.356	-.073	-.086	-122
05/01/80	3	170855	40	13.7	12.9	8.2	9.2	3.32E-01	.088	.026	-.031	50
05/02/80	4	112320	40	11.9	14.0	7.7	9.9	-1.03E+00	.107	-.084	-.089	-10
05/02/80	5	140520	40	12.3	13.1	7.7	9.3	-9.26E-02	.226	-.030	-.060	-108
05/02/80	6	172112	40	12.2	13.4	7.6	9.6	-2.00E-01	.188	-.047	-.073	-50
05/02/80	7	190324	40	12.2	13.0	7.7	9.3	-1.07E-01	.212	-.030	-.060	-93
05/03/80	8	101320	40	11.3	14.3	7.4	10.1	-1.71E+00	.100	-.123	-.115	-6
05/03/80	9	164510	40	13.0	13.6	7.7	9.7	-6.49E-02	.254	-.023	-.073	-154
05/03/80	10	192825	40	12.6	13.2	7.6	9.4	-6.61E-02	.248	-.023	-.066	-151
05/04/80	11	94432	40	11.7	14.7	7.5	10.4	-1.32E+00	.114	-.122	-.119	-6
05/05/80	12	100018	40	12.5	14.8	7.8	10.4	-8.04E-01	.128	-.091	-.107	-12
05/05/80	13	165536	40	13.8	13.5	8.5	9.6	1.61E-03	.528	.010	-.038	6194
05/06/80	14	91440	40	12.9	13.6	7.3	9.7	-4.89E-02	.322	-.028	-.085	-205
05/06/80	15	120213	40	12.8	13.2	7.4	9.4	-1.66E-02	.419	-.013	-.071	-601
05/06/80	16	161810	40	13.0	13.6	7.1	9.7	-2.29E-02	.453	-.023	-.094	-437
05/07/80	17	123620	40	12.4	14.0	7.5	9.9	-1.41E-01	.255	-.061	-.090	-71
05/07/80	18	175450	30	12.1	14.2	7.6	10.1	-1.72E-01	.256	-.078	-.094	-58
05/08/80	22	180800	30	12.7	14.2	7.5	10.0	-5.16E-02	.404	-.055	-.092	-174
05/08/80	23	190132	30	12.7	13.9	7.5	9.8	-4.43E-02	.394	-.043	-.084	-226
05/09/80	24	100900	30	13.8	14.8	8.2	10.5	-7.51E-02	.287	-.038	-.085	-133
05/09/80	25	114750	30	14.3	14.4	8.2	10.2	1.93E-02	.302	-.004	-.070	-518

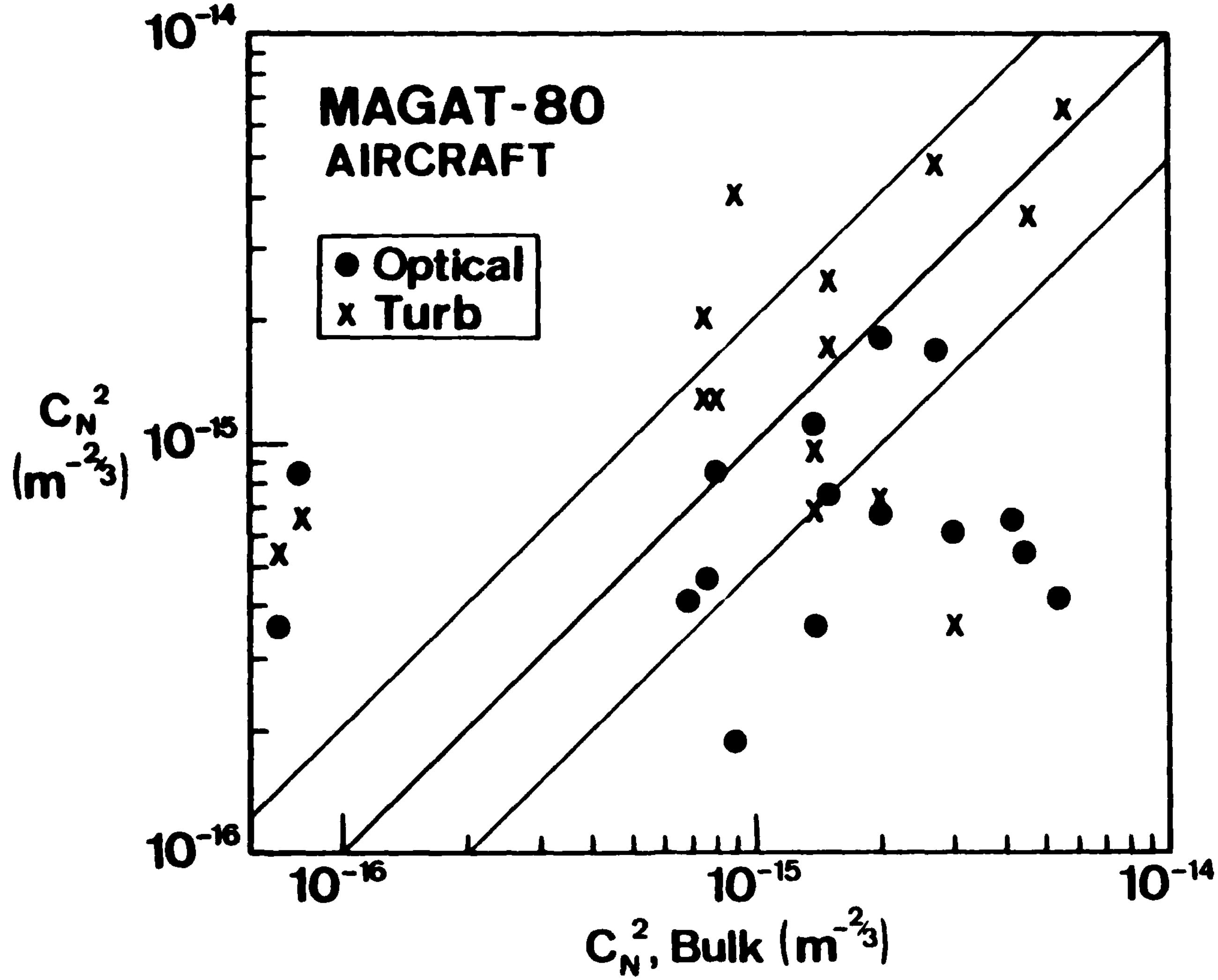

Figure 3. Comparison of aircraft turbulence C_N^2 values (X) and optically measured C_N^2 values (●) with C_N^2 calculated using the bulk method. The dark solid line indicates perfect agreement and the lighter lines indicate factor of two limits.

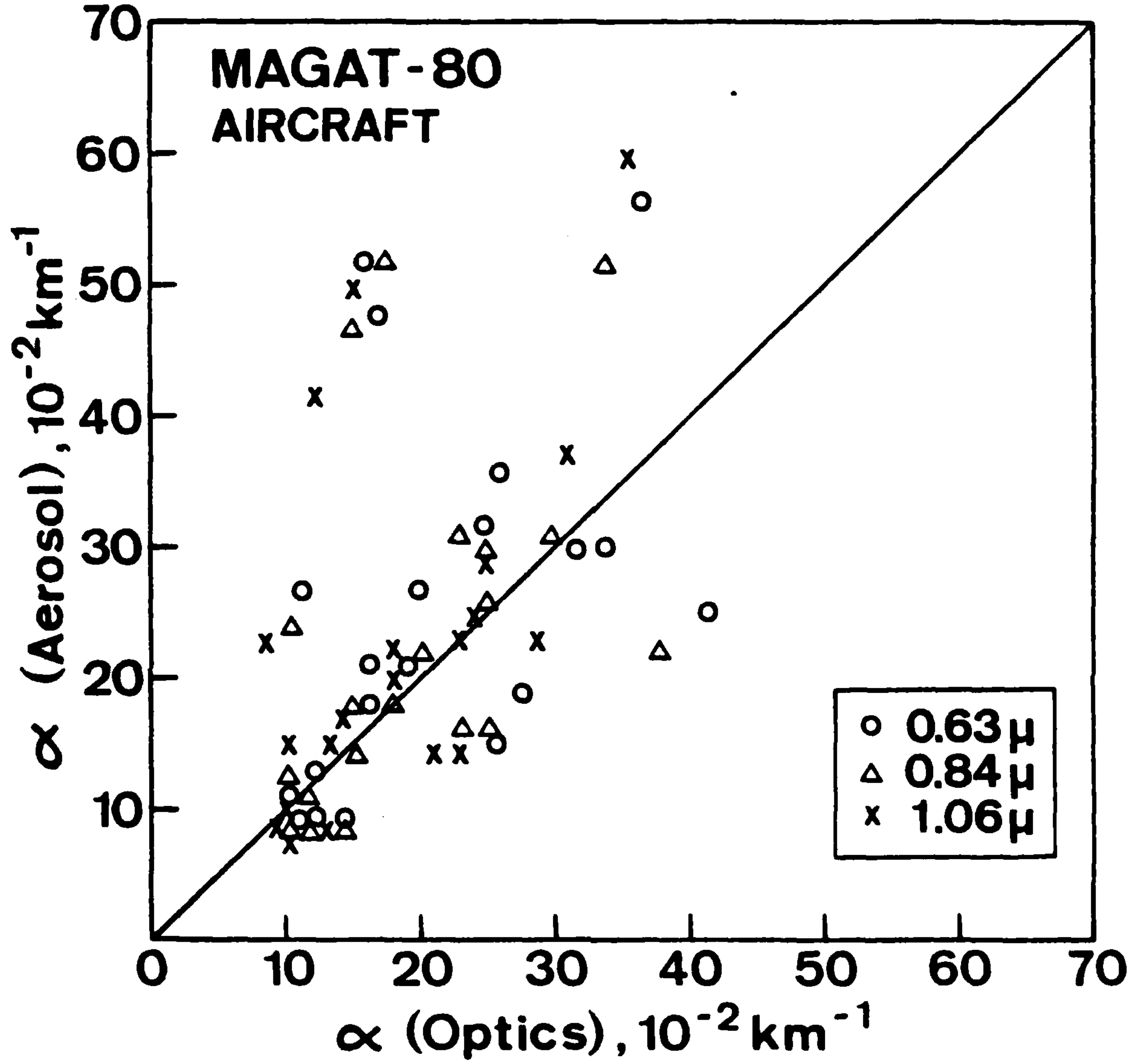

Figure 4. Comparison of optically measured extinction coefficient and aerosol extinction coefficient from aircraft optical path data.

3. Ship Extinction Comparison

The ship aerosol measurements were made at anchor along the optical path or underway within the square indicated in Fig. 2. Selected time series plots of extinction coefficients are given in Fig. 5a - 5g. Direct comparisons of size spectral and optical extinction values are given in Fig. 6a - 6d.

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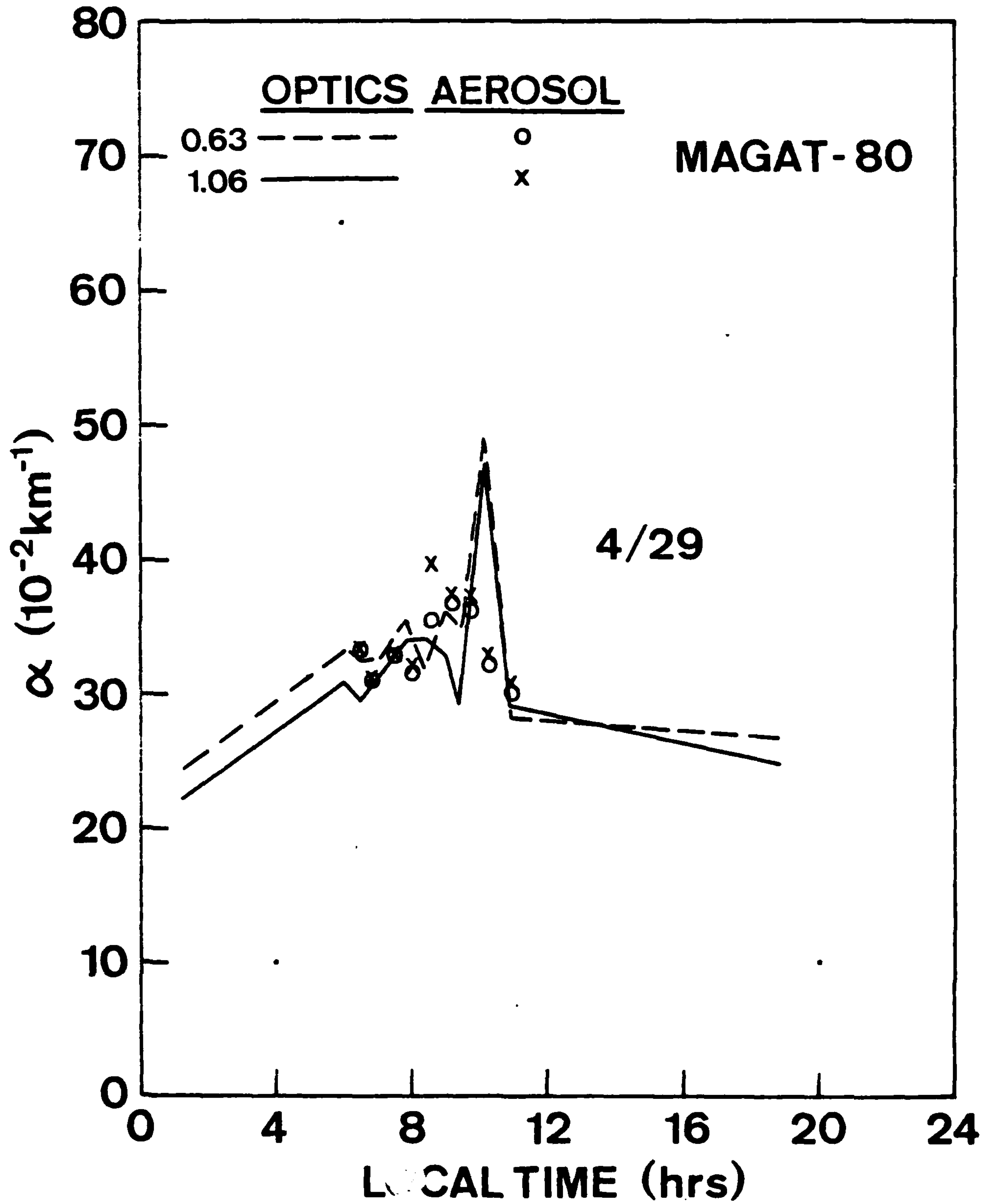

Figure 5a. Time series plot of aerosol extinctions coefficient from optical measurements (lines) and aerosol size spectra (X and O).

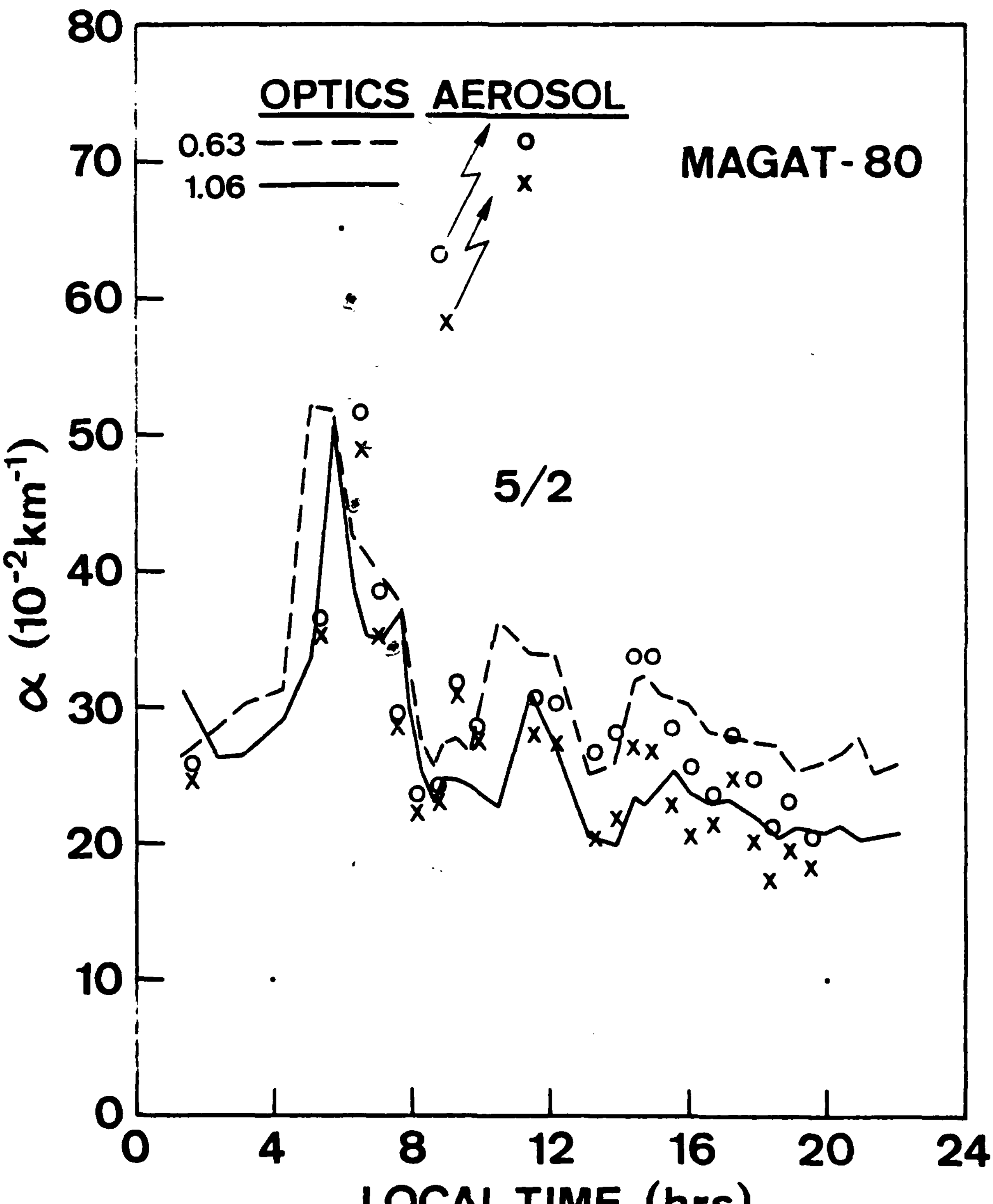

Figure 5b. Time series plot of aerosol extinctions coefficient from optical measurements (lines) and aerosol size spectra (X and O).

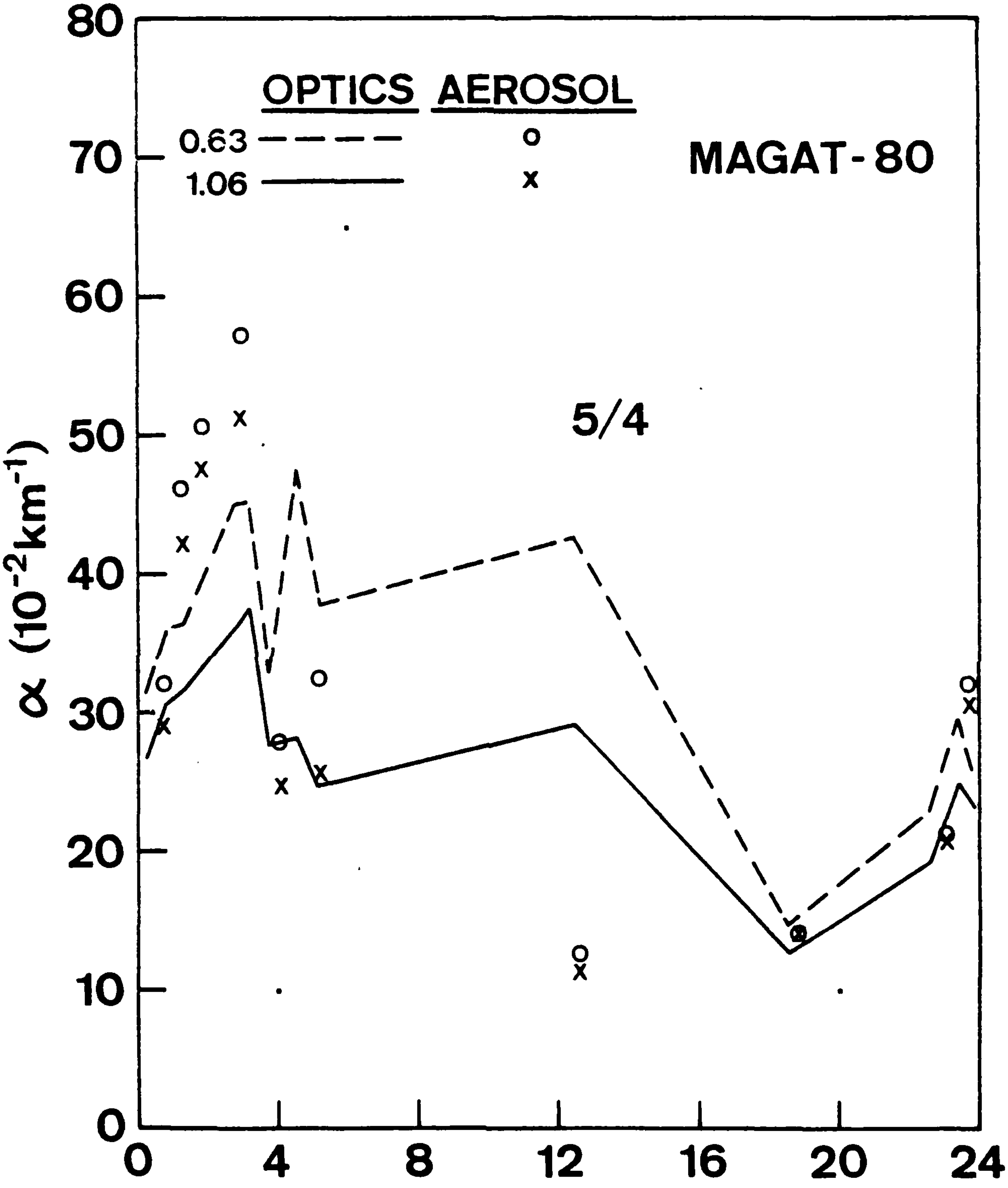

Figure 5c. Time series plot of aerosol extinctions coefficient from optical measurements (lines) and aerosol size spectra (X and O).

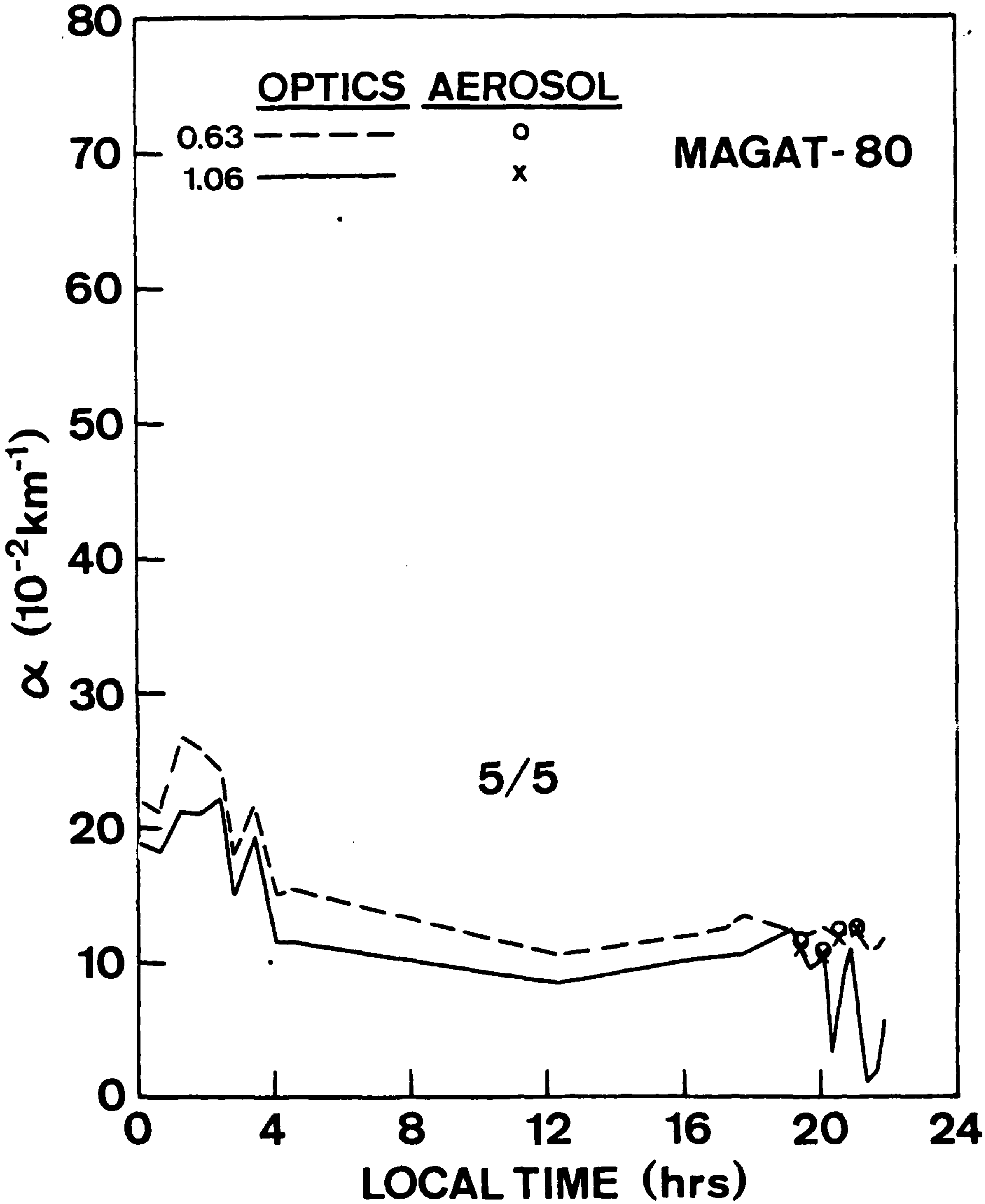

Figure 5d. Time series plot of aerosol extinctions coefficient from optical measurements (lines) and aerosol size spectra (X and O).

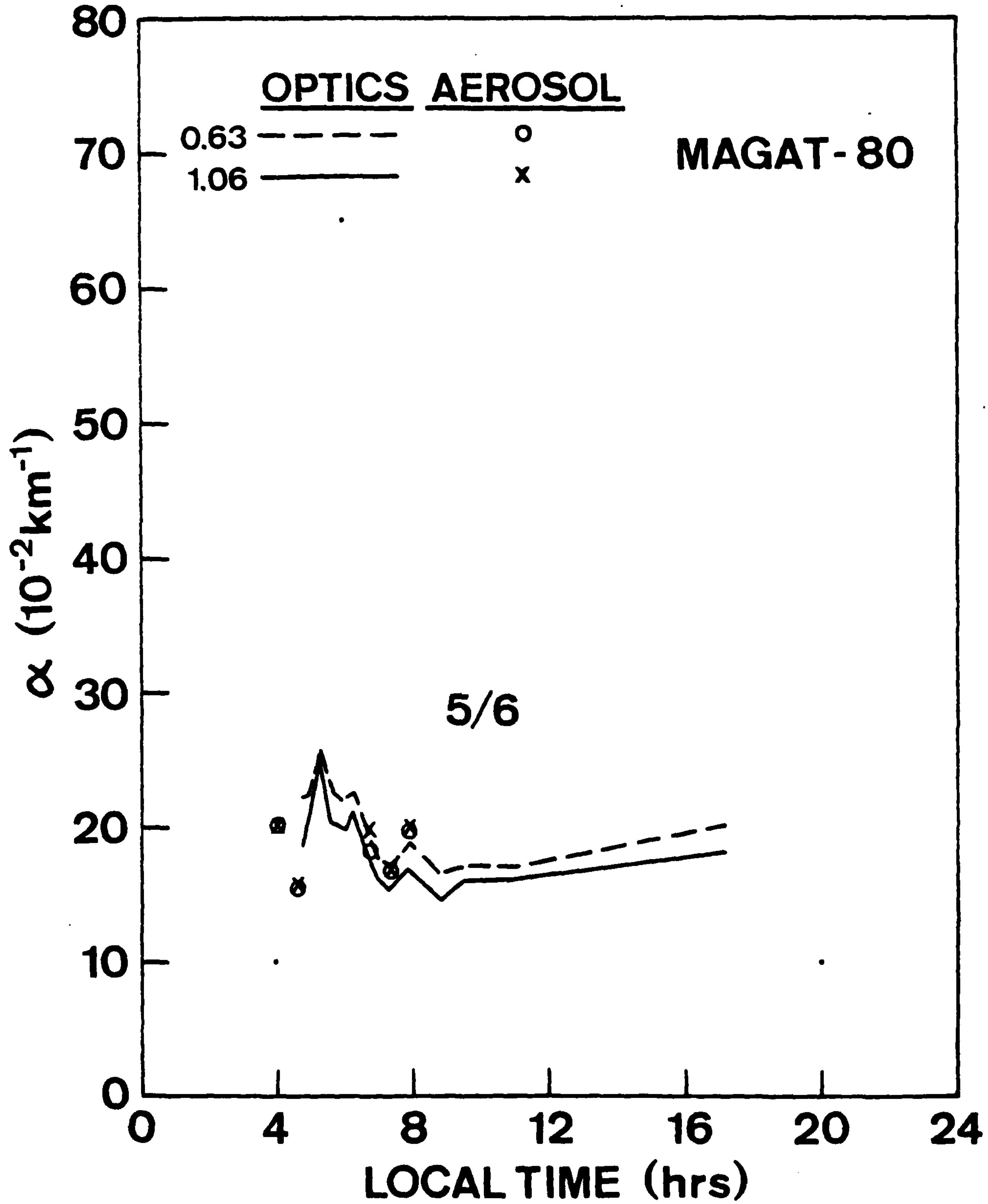

Figure 5e. Time series plot of aerosol extinctions coefficient from optical measurements (lines) and aerosol size spectra (X and O).

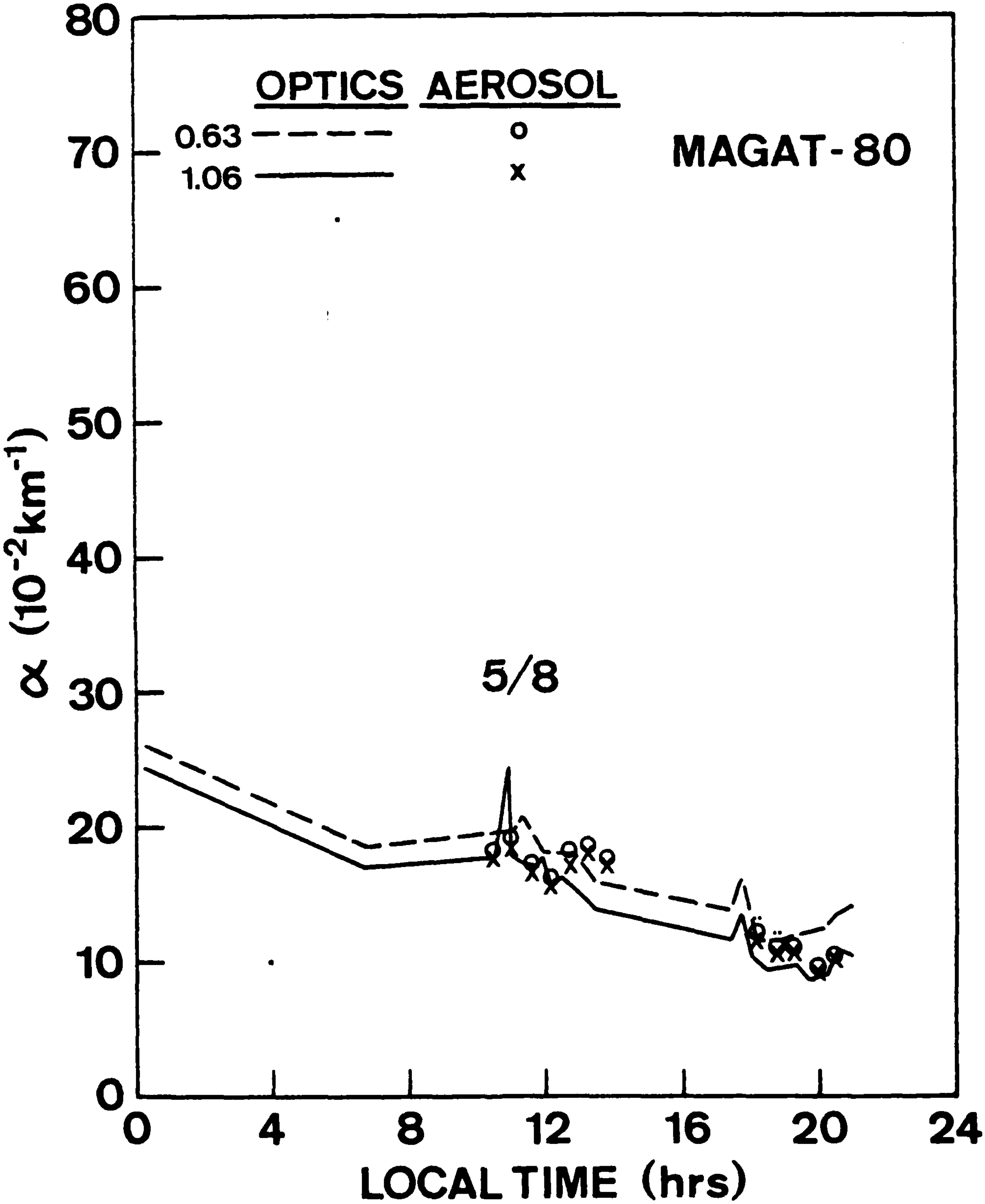

Figure 5f. Time series plot of aerosol extinctions coefficient from optical measurements (lines) and aerosol size spectra (X and O).

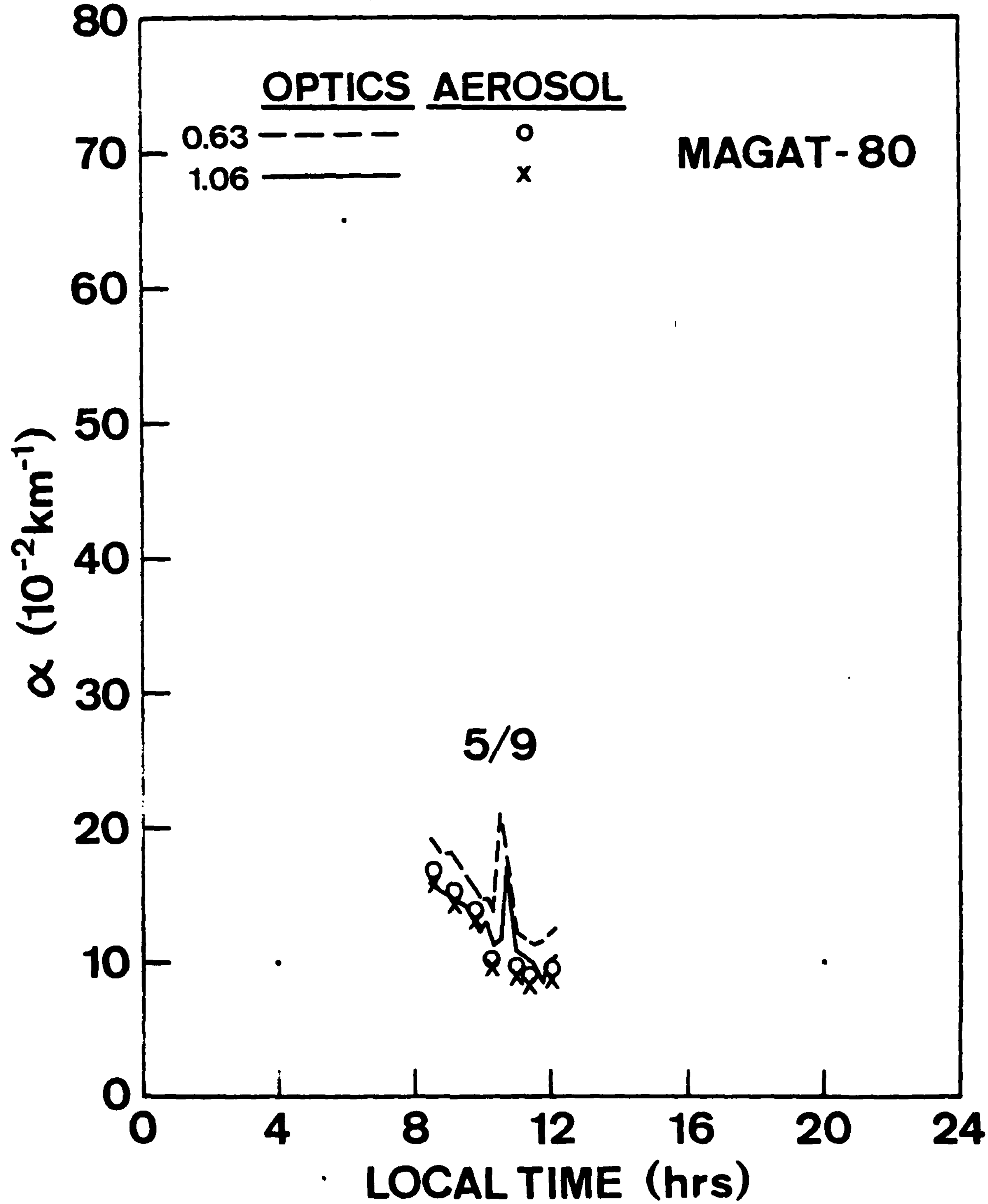

Figure 5g. Time series plot of aerosol extinctions coefficient from optical measurements (lines) and aerosol size spectra (X and O).

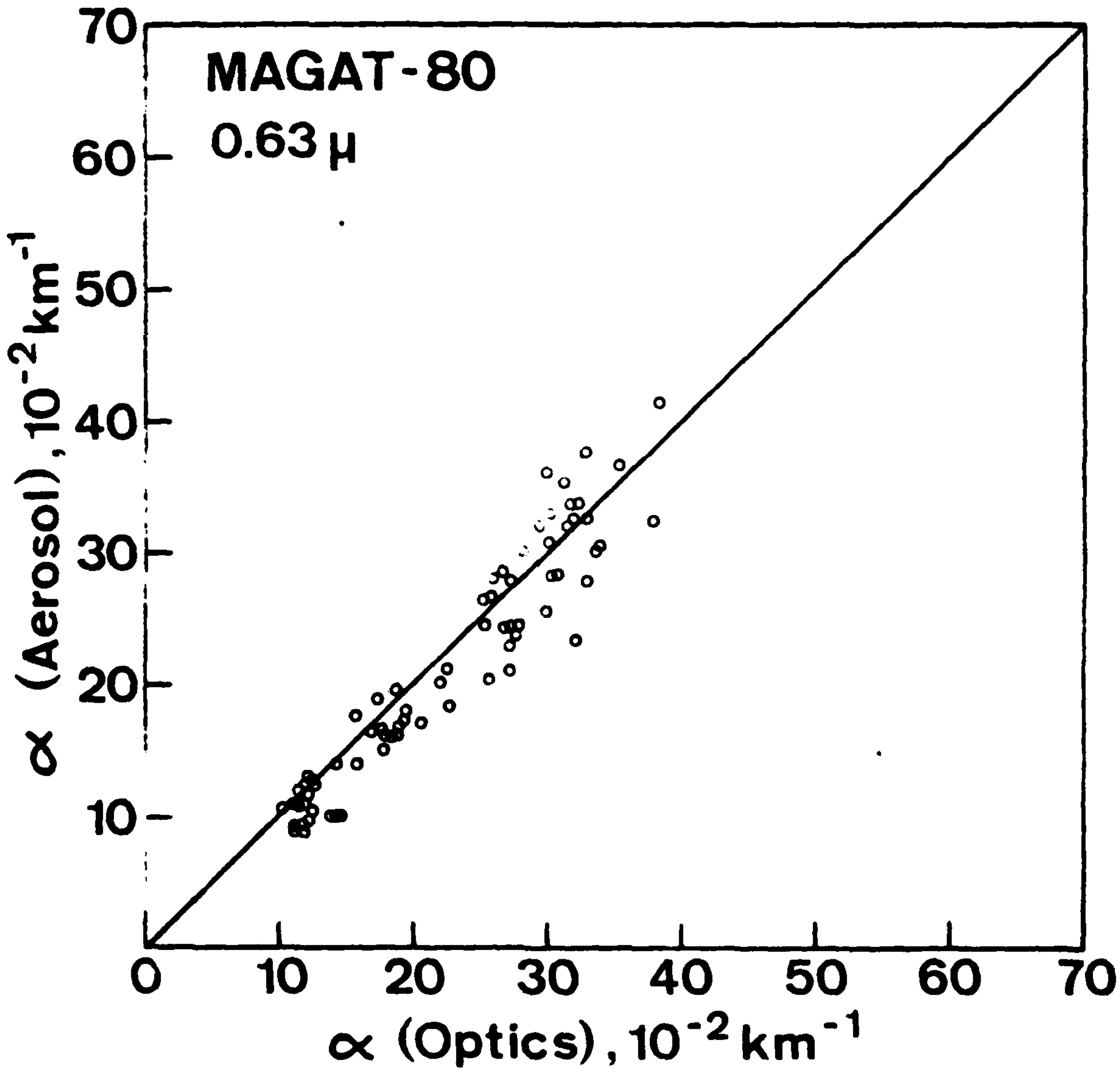

Figure 6a. Comparison of aerosol extinction coefficient from optical and aerosol size spectra measurements at $\lambda = 0.63\,\mu$.

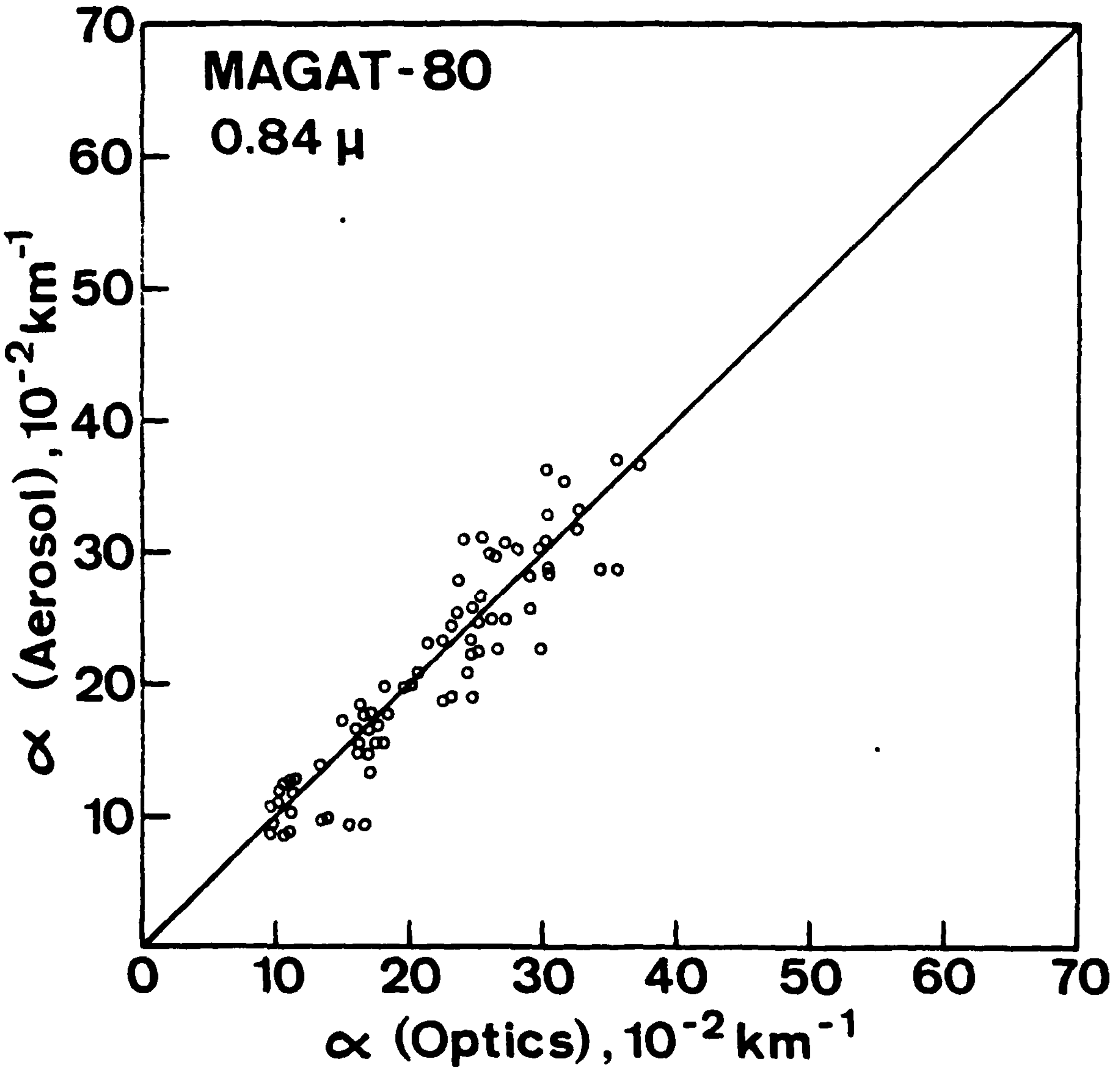

Figure 6b. Comparison of aerosol extinction coefficient from optical and aerosol size spectra measurements at $\lambda = 0.84\,\mu$.

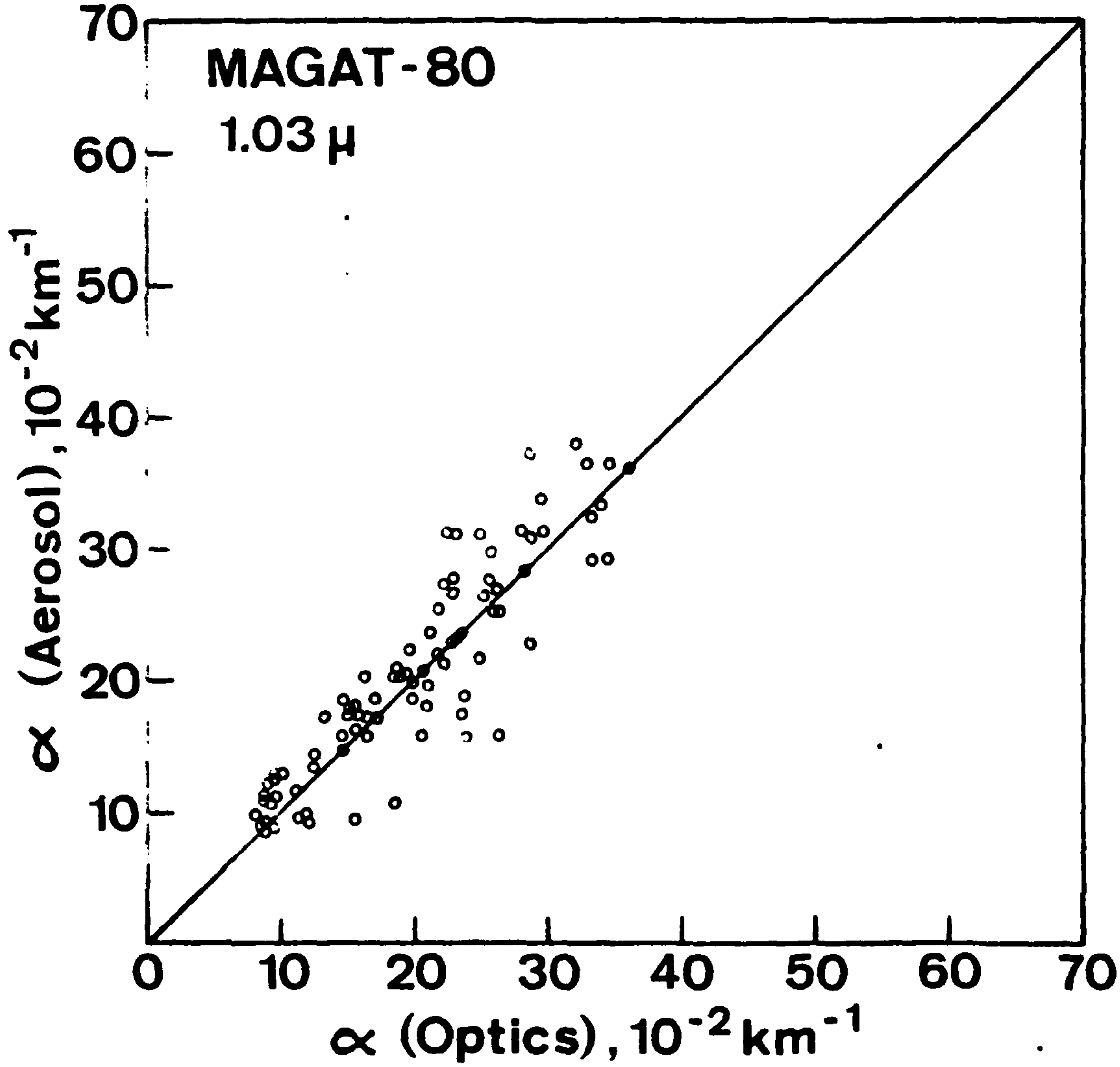

Figure 6c. Comparison of aerosol extinction coefficient from optical and aerosol size spectra measurements at $\lambda = 1.03\,\mu$.

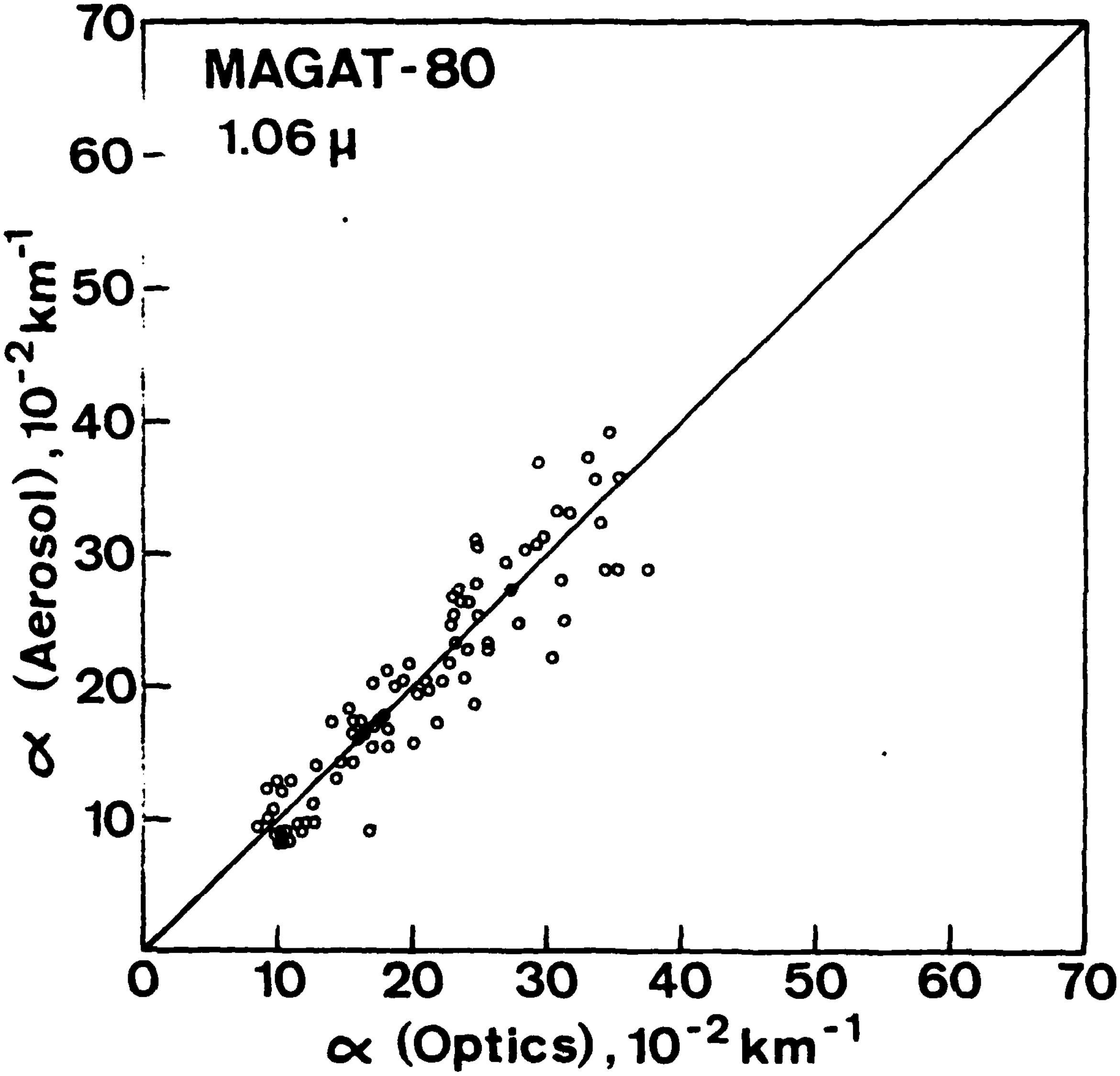

Figure 6d. Comparison of aerosol extinction coefficient from optical and aerosol size spectra measurements at $\lambda = 1.06\ \mu$.

APPENDIX A

Aircraft bulk meteorology and turbulence data on optical path in Monterey Bay.

ALT , Altitude (ft)

PRES , Pressure (mb)

T-ROS, Temperature (cent)

T-SIR, Sea surface temperature (cent)

T-DEW, Dew point (cent)

q , Water vapor mixing ratio (g/Kg)

EPS , Turbulence dissipation ratio (m^2/sec^3)

CT2 , Temperature structure function ($K^2/m^2/3$)

CQ2 , Water vapor structure function ($mb^2/m^2/3$)

EXT , Aerosol extinction, $\lambda = 0.49$ (km^{-1})

#	TIME	ALT	PRES	T_POS	T_STR	T_DEW	q	EPS	[illegible]	CO2	EXT
1	175155	40	1017.9	12.24	14.93	9.76	7.51	3.79E-03	6.72E-03	7.36E-03	1.19E-01
2	142010	40	1015.4	12.02	14.13	10.18	7.74	1.21E-02	3.70E-03	2.76E-03	1.81E-01
3	170855	40	1022.1	13.59	12.86	11.10	8.18	1.76E-11	9.58E-04	1.61E-03	1.96E-02
4	112320	40	1024.8	11.78	13.96	10.19	7.67	5.35E-04	1.69E-03	7.74E-03	1.02E-01
5	140520	40	1023.4	12.19	13.12	10.28	7.73	3.13E-03	1.22E-03	6.17E-03	1.22E-01
6	172112	40	1022.4	12.08	13.45	10.08	7.64	1.97E-03	2.51E-03	3.48E-03	6.17E-02
7	190324	40	1023.4	12.10	13.03	10.19	7.69	2.60E-03	1.34E-03	1.90E-03	5.56E-02
8	101320	40	1022.4	11.20	14.26	9.53	7.35	5.25E-04	8.61E-04	4.98E-01	7.45E-02
9	164510	40	1021.3	12.91	13.65	10.20	7.71	4.29E-03	1.18E-03	3.44E-03	3.01E-01
10	192825	40	1022.4	12.46	13.21	10.01	7.60	3.99E-03	3.43E-03	2.16E-03	1.56E-01
11	94432	40	1021.4	11.58	14.65	9.74	7.47	6.93E-04	5.89E-04	6.83E-02	1.69E-01
12	100018	40	1022.7	12.38	14.77	10.34	7.77	8.29E-04	1.33E-06	3.59E-03	1.84E-01
13	165219	10	1023.0	13.80	13.42	11.77	8.55	1.06E-01	1.81E-03	1.11E-01	1.02E-01
13	165536	40	1022.2	13.64	13.48	11.72	8.53	3.61E-02	6.42E-04	1.10E-02	8.27E-02
14	91440	40	1022.8	12.76	13.65	9.52	7.35	8.62E-03	4.15E-03	1.10E-02	1.40E-01
15	120213	40	1022.9	12.71	13.20	9.73	7.45	1.80E-02	1.95E-03	3.13E-03	1.44E-01
16	164810	40	1022.6	12.86	13.62	8.98	7.08	2.30E-02	3.04E-03	4.80E-03	1.57E-01
16	165540	40	1022.8	12.78	12.67	8.95	7.07	4.71E-02	2.16E-03	4.38E-03	1.73E-01
17	123620	40	1020.2	12.24	14.00	9.86	7.54	4.67E-03	4.98E-03	4.01E-03	2.40E-01
18	175110	10	1019.7	12.20	14.26	9.95	7.59	7.46E-03	6.30E-03	7.23E-03	2.15E-01
18	175450	30	1019.0	12.00	14.17	9.89	7.56	5.61E-03	3.66E-03	3.62E-03	2.10E-01
18	175945	60	1018.2	11.92	14.02	9.84	7.54	3.70E-03	1.92E-03	3.46E-03	2.09E-01

#	TIME	ALT	PRES	T_ROS	T_SIR	T_DEW	q	EPS	CT2	CN2	EZI
19	104320	10	1023.3	-.67	16.00	9.32	7.24	4.36E-03	5.87E-04	1.44E-02	1.78E-01
19	104719	30	1023.1	-.67	15.79	9.16	7.17	2.45E-03	3.62E-04	9.35E-03	1.23E-01
19	105252	60	1022.5	-.68	15.62	9.03	7.11	1.61E-03	2.18E-04	6.86E-03	1.39E-01
19	110035	50	1023.1	-.68	14.60	9.10	7.14	3.41E-03	1.67E-04	6.66E-03	1.23E-01
20	125943	10	1024.6	-.58	15.05	9.43	7.29	8.11E-03	4.02E-04	9.69E-03	1.51E-01
20	130518	30	1023.9	-.59	14.71	9.35	7.26	4.24E-03	2.41E-04	3.67E-03	1.11E-01
20	130930	60	1022.8	-.60	14.90	9.22	7.20	2.97E-03	2.15E-04	3.02E-03	1.14E-01
20	131913	100	1021.7	-.61	13.50	9.04	7.12	5.62E-03	1.87E-04	2.87E-03	1.18E-01
22	180408	10	1022.4	12.50	13.71	10.14	7.67	3.14E-02	6.62E-04	2.20E-01	8.04E-02
22	180800	30	1021.5	12.58	14.18	9.88	7.54	2.16E-02	5.55E-04	1.50E-02	7.36E-02
22	181345	60	1021.1	12.43	13.69	9.87	7.54	1.20E-02	3.43E-04	1.11E-02	7.23E-02
22	181940	60	1021.2	12.39	12.93	9.98	7.59	2.77E-02	6.30E-04	2.51E-02	6.91E-02
23	185750	10	1022.4	12.65	14.03	10.03	7.61	4.05E-02	8.03E-04	9.81E-01	6.54E-02
23	190132	30	1021.5	12.57	13.85	9.84	7.52	1.79E-02	4.21E-04	1.42E-01	6.46E-02
23	190640	60	1020.4	12.36	13.74	9.74	7.48	1.21E-02	2.47E-04	9.68E-02	6.30E-02
24	100325	10	1021.4	13.78	15.22	11.14	8.21	4.76E-11	2.14E-03	3.19E-02	6.40E-02
24	100900	30	1020.8	13.70	14.82	11.05	8.16	4.49E-11	8.40E-04	2.45E-02	6.72E-02
24	101638	60	1019.8	13.65	14.59	10.83	8.05	4.27E-11	6.57E-04	1.76E-02	6.36E-02
24	102455	100	1018.5	12.83	13.12	11.33	8.34	4.06E-11	8.86E-04	3.15E-02	1.52E-01
25	114405	10	1021.3	14.13	14.45	11.26	8.28	1.43E-02	5.61E-04	2.61E-02	5.88E-02
25	114750	30	1020.8	14.19	14.38	11.20	8.25	7.75E-03	5.39E-04	1.61E-02	6.39E-02
25	115400	60	1019.7	14.07	14.15	11.14	8.23	5.22E-03	3.18E-04	1.45E-02	6.28E-02

APPENDIX B

Summary of aircraft optical measurements in Monterey Bay.

ALT	,	Altitude (ft)
PRES	,	Pressure (mb)
T-ROS	,	Temperature (cent)
T-DEW	,	Dew point (cent)
CN2T	,	C_T^2 component of C_N^2 ($m^{-2/3}$)
CN2	,	Turbulence value of C_N^2 ($m^{-2/3}$)
E(.63)	,	Aerosol extinction (Km^{-1}) at $\lambda = 0.63$
E(.84)	,	Aerosol extinction (Km^{-1}) at $\lambda = 0.84$
E(1.06)	,	Aerosol extinction (Km^{-1}) at $\lambda = 1.06$

DATE	#	TIME	ALT	PRES	T BOS	T DEW	CN2*	CN2	E(.63)	E(.84)	E(1.06)
04/2[illegible]/80	1	1[illegible]3115	40	1017.9	12.24	9.76	6.6E-15	6.7E-15	1.3E-01	9.7E-02	7.2E-02
04/30/80	2	142010	40	1015.4	12.02	10.18	3.6E-15	3.6E-15	1.5E-01	1.1E-01	8.5E-02
05/01/80	3	120[illegible]	40	1022.1	13.59	11.10	9.5E-16	9.5E-16	1.4E-02	9.1E-03	6.2E-03
05/02/80	4	11[illegible]0	40	1024.8	11.78	10.19	1.7E-15	1.7E-15	8.3E-02	6.1E-02	4.7E-02
05/02/80	5	140520	40	1023.4	12.19	10.28	1.3E-15	1.3E-15	7.5E-02	4.4E-02	2.9E-02
05/02/80	6	172112	40	1022.4	12.08	10.08	2.5E-15	2.5E-15	4.9E-02	3.3E-02	2.4E-02
05/03/80	7	190324	40	1023.4	12.10	10.19	1.3E-15	1.3E-15	4.4E-02	3.1E-02	2.2E-02
05/03/80	8	101320	40	1022.4	11.20	9.53	8.5E-16	1.9E-15	5.9E-02	4.2E-02	3.0E-02
05/03/80	9	164510	40	1021.3	12.91	10.20	1.2E-15	1.2E-15	2.2E-01	1.5E-01	1.1E-01
05/03/80	10	192825	40	1022.4	12.46	10.01	3.4E-15	3.4E-15	1.3E-01	9.7E-02	7.3E-02
05/04/80	11	94432	40	1021.4	11.58	9.74	5.8E-16	7.2E-16	1.4E-01	1.1E-01	8.7E-02
05/05/80	12	100018	40	1022.7	12.38	10.34	1.3E-18	8.6E-18	1.6E-01	1.2E-01	9.4E-02
05/05/80	13	165219	10	1023.0	13.80	11.77	1.8E-15	2.0E-15	9.1E-02	7.3E-02	5.9E-02
05/05/80	13	165536	40	1022.2	13.64	11.72	6.3E-16	6.6E-16	7.2E-02	5.6E-02	4.4E-02
05/06/80	14	91440	40	1022.8	12.76	9.52	4.1E-15	4.1E-15	1.2E-01	8.9E-02	6.8E-02
05/06/80	15	120213	40	1022.9	12.71	9.73	1.9E-15	1.9E-15	1.2E-01	9.5E-02	7.5E-02
05/06/80	16	164810	40	1022.6	12.86	8.98	3.0E-15	3.0E-15	1.3E-01	1.0E-01	8.1E-02
05/06/80	16	165540	40	1022.8	12.78	8.95	2.1E-15	2.1E-15	1.5E-01	1.1E-01	9.2E-02
05/07/80	17	123620	40	1020.2	12.24	9.86	4.9E-15	4.9E-15	2.0E-01	1.5E-01	1.2E-01
05/07/80	18	175110	10	1019.7	12.20	9.95	6.2E-15	6.2E-15	1.8E-01	1.4E-01	1.1E-01
05/07/80	18	175450	30	1019.0	12.00	9.89	3.6E-15	3.6E-15	1.8E-01	1.3E-01	9.8E-02
05/07/80	18	175945	60	1018.2	11.92	9.84	1.9E-15	1.9E-15	1.8E-01	1.3E-01	1.0E-01

DATE	#	TIME	ALT	PRES	T ROS	T DEW	CN2T	CN2	E(.63)	E(.84)	E(1.06)
05/08/80	19	104320	10	1023.3	-.67	9.32	5.8E-16	6.1E-16	1.1E-01	7.9E-02	6.2E-02
05/08/80	19	104719	30	1023.1	-.67	9.16	3.6E-16	3.8E-16	1.0E-01	7.5E-02	5.8E-02
05/08/80	19	105252	60	1022.5	-.68	9.03	2.2E-16	2.3E-16	1.2E-01	9.4E-02	7.8E-02
05/08/80	19	110035	50	1023.1	-.68	9.10	1.7E-16	1.8E-16	9.6E-02	6.4E-02	4.5E-02
05/08/80	20	125943	10	1024.6	-.58	9.43	4.0E-16	4.2E-16	1.3E-01	9.1E-02	6.7E-02
05/08/80	20	130518	30	1023.9	-.59	9.35	2.4E-16	2.5E-16	9.4E-02	6.9E-02	5.3E-02
05/08/80	20	130930	60	1022.8	-.60	9.22	2.1E-16	2.2E-16	9.7E-02	7.3E-02	5.7E-02
05/08/80	20	131913	100	1021.7	-.61	9.04	1.8E-16	1.9E-16	9.9E-02	7.3E-02	5.6E-02
05/08/80	22	180408	10	1022.4	12.50	10.14	6.5E-16	1.1E-15	6.9E-02	5.3E-02	4.2E-02
05/08/80	22	180800	30	1021.5	12.58	9.89	5.5E-16	5.8E-16	6.2E-02	4.7E-02	3.7E-02
05/08/80	22	181345	60	1021.1	12.43	9.87	3.4E-16	3.6E-16	6.1E-02	4.7E-02	3.7E-02
05/08/80	22	181940	60	1021.2	12.39	9.98	6.2E-16	6.7E-16	5.9E-02	4.4E-02	3.4E-02
05/08/80	23	185750	10	1022.4	12.65	10.03	7.9E-16	2.8E-15	5.4E-02	3.9E-02	3.0E-02
05/08/80	23	190132	30	1021.5	12.57	9.84	4.2E-16	7.0E-16	5.4E-02	3.9E-02	3.0E-02
05/08/80	23	190640	60	1020.4	12.36	9.74	2.4E-16	4.4E-16	5.3E-02	3.9E-02	3.0E-02
05/09/80	24	100325	10	1021.4	13.78	11.14	2.1E-15	2.2E-15	5.2E-02	3.9E-02	3.0E-02
05/09/80	24	100900	30	1020.8	13.70	11.05	8.3E-16	8.8E-16	5.5E-02	4.1E-02	3.1E-02
05/09/80	24	101638	60	1019.8	13.65	10.83	6.5E-16	6.8E-16	5.2E-02	3.8E-02	2.9E-02
05/09/80	24	102455	100	1018.5	12.83	11.33	8.7E-16	9.3E-16	1.3E-01	1.1E-01	9.7E-02
05/09/80	25	114405	10	1021.3	14.13	11.26	5.5E-16	6.1E-16	4.6E-02	3.2E-02	2.4E-02
05/09/80	25	114750	30	1020.8	14.19	11.20	5.3E-16	5.6E-16	5.1E-02	3.5E-02	2.5E-02
05/09/80	25	115400	60	1019.7	14.07	11.14	3.1E-16	3.4E-16	5.0E-02	3.5E-02	2.5E-02

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